Characterizing and Treating Lane Discontinuities on North Carolina Streets and Highways

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ABSTRACT
Lane continuity is thought to be important to safe and efficient operations, but violations are surprisingly common. In North Carolina, concern about the number of lane discontinuities, and their growth, spurred an effort to characterize lane discontinuities and develop a policy on removing the existing ones and preventing new ones.

In response to a request from the authors, NCDOT engineers provided 30 documented lane discontinuities. While not a complete or random sample, the cases should be illustrative. The cases were scattered in urban or suburban areas from Asheville to Wilmington. There were 12 cases on interstates, six on US routes, three on NC routes, and nine on secondary routes. Ten cases had one basic through lane and 17 had two basic through lanes.

The most common discontinuity was a lane add then a lane drop. A lane drop followed by a lane add was less common. Five of the 30 cases were left lane drops.

The average distance between the lane add and drop, or the drop and add, was 1.9 miles. Well over half of the cases had a distance under 3500 feet. In one case through drivers must make a lane change within 400 feet.

Lane discontinuities were created for a wide variety of reasons, including construction projects, land development, and route number changes.

Informed by the sample described above, the NCDOT has crafted a policy on lane discontinuities. The policy has two parts, including to prevent new cases from being created and to encourage the removal of existing cases.

INTRODUCTION

Lane continuity is a traditional concept in traffic engineering and roadway design in which drivers should not have to change lanes to keep following a certain route. The concept applies most importantly on primary (two-digit) interstate routes, with high proportions of longer-distance travelers, but applies to some extent on all roadways with more than one through lane in a direction. Lane continuity, "helps meet driver expectations, avoid driver confusion, and ultimately eliminate collisions" (Hummer, 2011).

Unfortunately, on North Carolina roadways there are too many lane discontinuities, and more lane discontinuities seem to be created each year. Lane discontinuities on North Carolina roadways undoubtedly cause undue stress to drivers, make drivers change lanes that otherwise would prefer not to, and cause crashes.

Concern about the number of lane discontinuities on NC highways, and their growth, spurred an effort to characterize lane discontinuities and develop a policy on their removal. The purpose of this policy is to reduce the number of lane discontinuities on North Carolina roadways. The ultimate goal is to eliminate all lane discontinuities. Making sure that the Department does not create more new lane discontinuities is a good first step toward that ultimate goal. This paper describes the extent of the problem on NC roadways currently and details the policy we developed to treat the problem.

Related Concepts

Lane continuity is not mentioned specifically in the AASHTO Green Book (1). The Green Book does say on page 10-72 that, "Consistency should be maintained in the number of lanes provided along any route of arterial character." The Green Book discusses route continuity, the basic number of lanes, and lane balance at length. Meanwhile, on page 297 the ITE *Traffic Engineering Handbook* (2) states that, "The principles of route continuity, lane continuity, lane balance, and maintaining the basic number of lanes must be considered collectively."

The concept of route continuity holds that an important route should be designed as the through route at an interchange or intersection regardless of its actual orientation. Figure 1 provides an example of route continuity. In a sense, route continuity is a special case of lane continuity, applying in the case of a route that changes direction while lane continuity applies at all junctions whether the route changes directions or not.

The concept of a basic number of lanes holds that over a long segment of important route, the number of through lanes in a direction should not change. If needed, auxiliary lanes can be added or dropped to handle variations in demand that happen over short distances, but dropping a through lane that has been continuous for a long distance, or adding a through lane that will be continuous for a long distance, should be rare.

The concept of lane balance has to do with how to handle multilane ramps and junctions. The concept is described in detail in the Green Book (1).

Figure 2 provides examples from Section 2.1.7 of the *Geometric Design Guide for Canadian Roads* (3) that illustrate the related concepts of lane continuity, basic number of lanes, and lane balance. Examples i, ii, and iv show good maintenance of the concepts, while example iii provides a case in which lane continuity and lane balance have been violated.

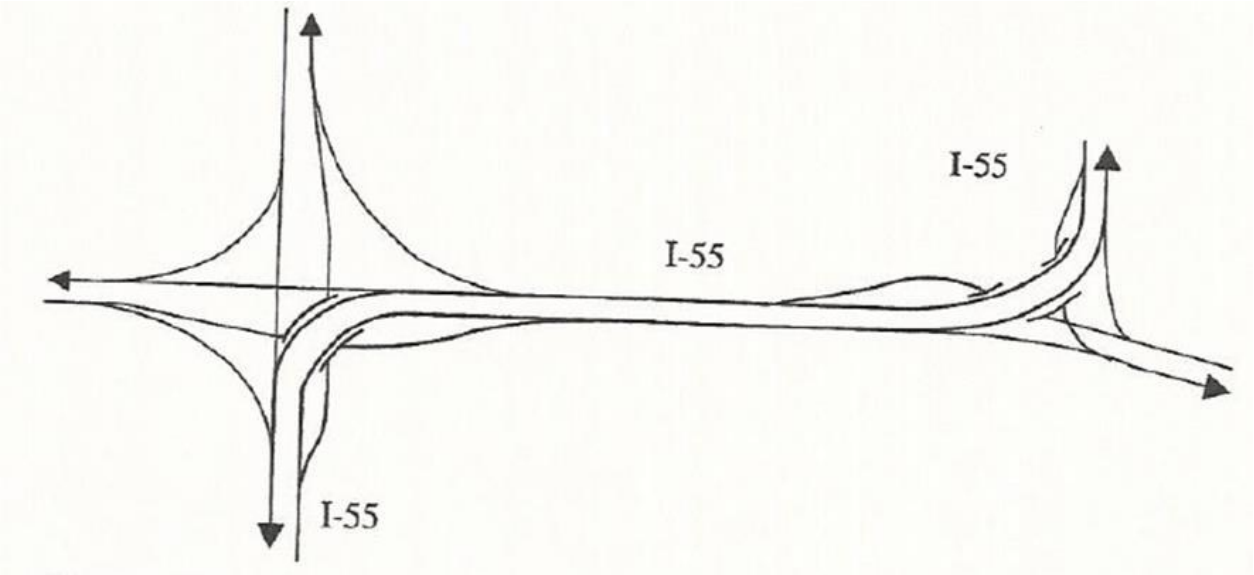


Figure 1. Example of route continuity (4).

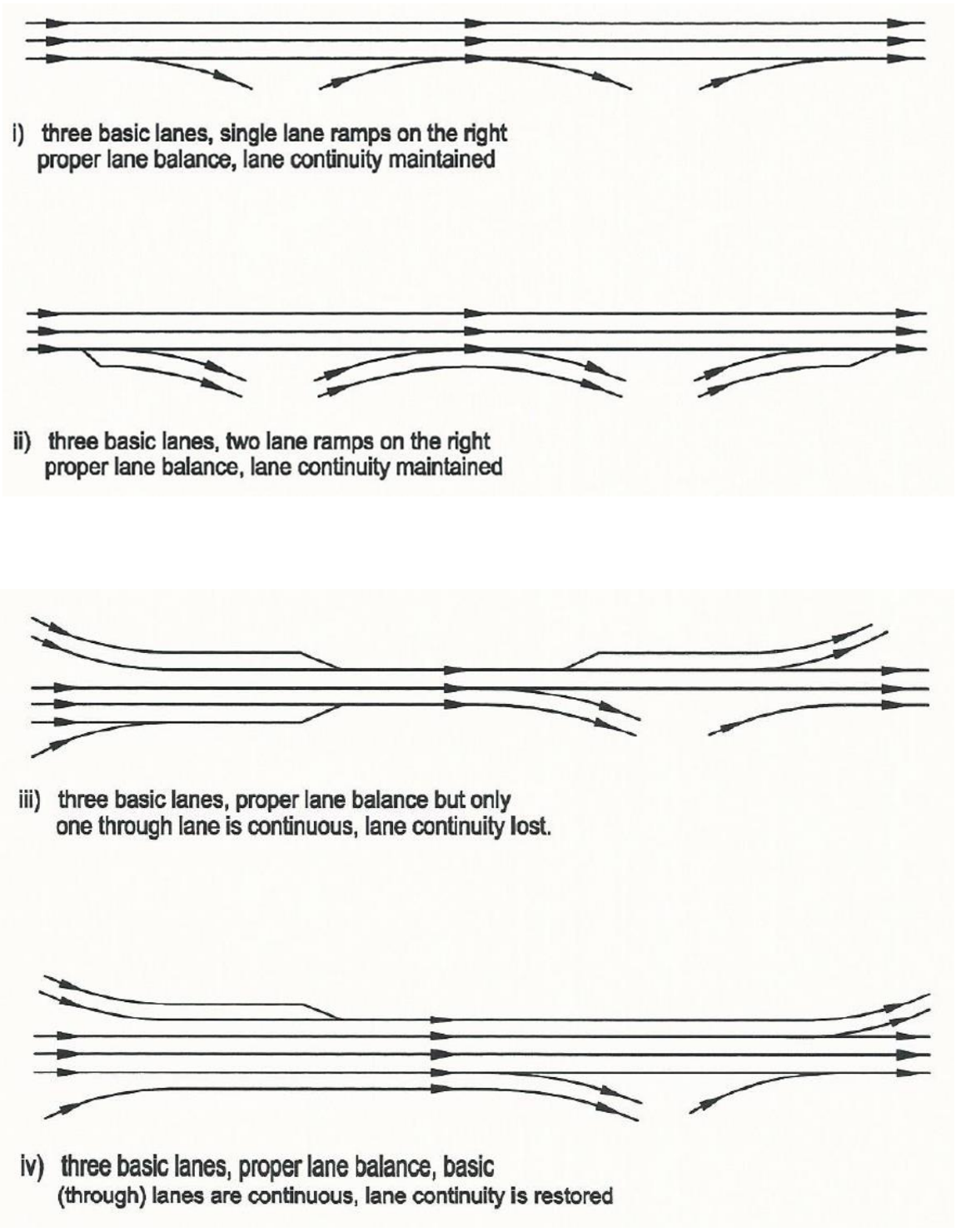


Figure 2. Examples of lane continuity, lane balance, and the basic number of lanes (3).

Delay

While the authors did not find any literature on this topic, it is obvious that substantial extra delay is caused at many places due to lane discontinuities. For example, Figure 3 shows congestion levels as reported by Google for a typical Tuesday a.m. peak hour on westbound I-540 in the northern portion of Raleigh. There is a well-known lane discontinuity on this segment. Westbound I-540 has three basic through lanes for its entire 26 miles except for 0.5 miles between the off ramp to US-1 and the on-ramp from US-1, within which westbound I-540 has just two through lanes. Sure enough, Google reports substantial congestion through and prior to the two-lane section.

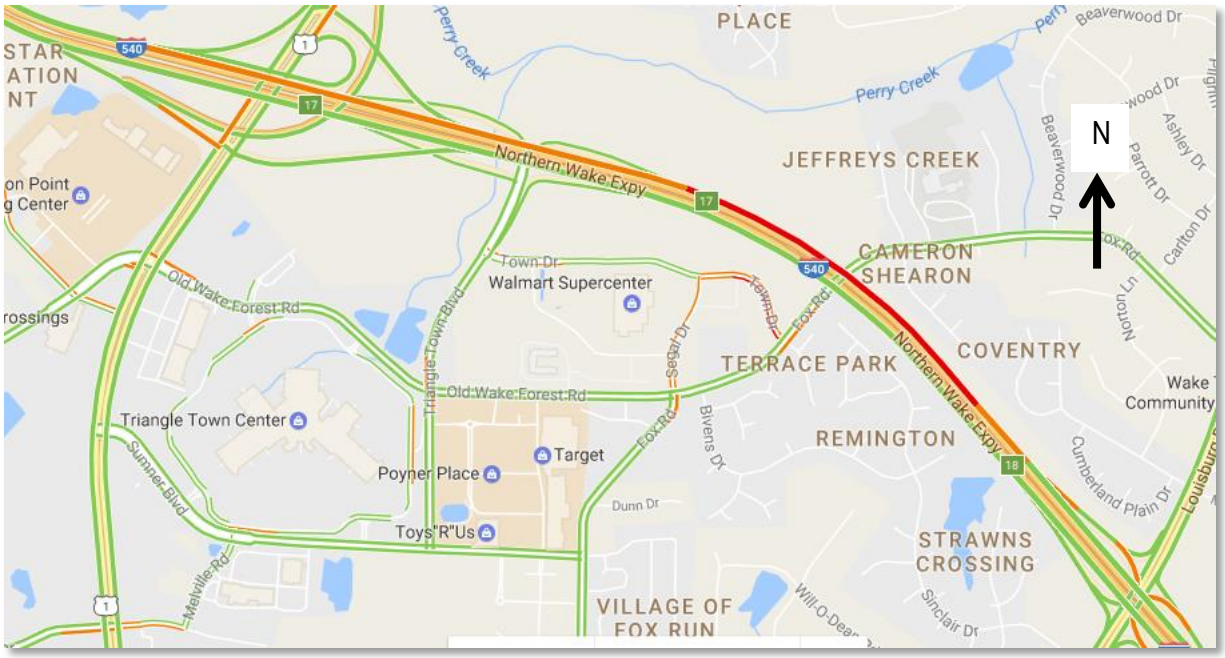


Figure 3. Congestion on westbound I-540, shown in orange and red, at lane discontinuity (Google).

Delay at lane discontinuities happens due to a lack of capacity, due to confused drivers making late lane changes, and due to inefficient uses of the lanes that are provided. Figure 4 shows a case from Apex, NC that results in inefficient use of available lanes. On the northbound side of the road, a through lane is added on the left side at a major shopping center access point shown in the picture while a through lane is dropped on the right side at the freeway entrance ramp about 1100 feet to the north. Consequently, northbound through drivers use the left through lane much more than the right through lane at the signal in Figure 4. This imbalance means longer queues in the left lane than if the lane usage was balanced and means that the signal phase serving the northbound through movement must remain green longer than it would otherwise.

Figure 4. Lane discontinuity in Apex, NC resulting in poor lane utilization (Google).

Crashes

While lane discontinuities lead to some delay, the most serious and tangible harm they cause is in extra crashes. Lane discontinuities force drivers to change lanes more often than they would with continuous lanes. In turn, this leads to crashes that are mostly categorized as sideswipes. In a comprehensive analysis for NHTSA, Sen at al. found in 2003 that lane change crashes make up about 4% of total number of reported crashes in the US (5). This equates to about 200,000 crashes per year. Sen et al. also found that over 50% of lane change crashes were on roads with speed limits of 45 mph or lower, and that 26% of lane change crashes were attributed by the investigator to driver distraction. Regarding the 26% statistic, since cell phone use is so much more prevalent now than in 2003 it is likely that this percentage is even higher today.

While lane change crashes represent only about four percent of all reported crashes, they tend to occur more often on busy roads. Jula, et al. (6) reported that lane change crashes are responsible for ten percent of all crash-caused delays on US highways. The fact that four percent of crashes cause ten percent of crash-caused delay likely is due to the fact that these types of crashes are occurring more often on busy roads.

No research has yet estimated the frequency of crashes caused by lane discontinuities or provided a model to estimate their occurrence. However, in 2009 Chen, et al. did publish results from a safety study of different interchange configurations which hints at the impacts of lane discontinuities (7). They developed crash prediction models for four types of interchanges in Florida. Interchanges with one-lane diverge ramps with lane drops had 68 percent more crashes at the diverge area than interchanges without lane drops. Interchanges with two-lane diverge ramps with lane drops had 32 percent more crashes at the diverge area than interchanges without lane drops. From these results, the potential for crash reduction by eliminating lane discontinuities is clear.

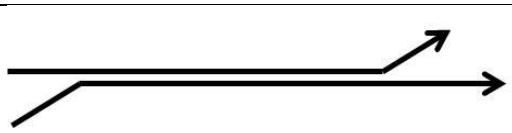
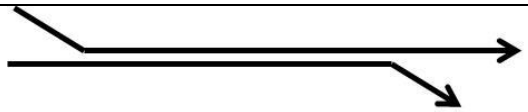
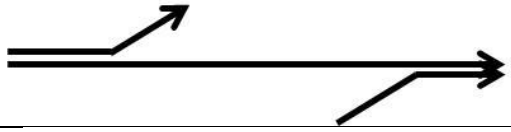
CASES IN NORTH CAROLINA

As noted above, unfortunately in North Carolina there are too many lane discontinuities in place. In June 2016, regional traffic engineers, division traffic engineers, roadway designers, and Mobility and Safety headquarters staff members responded to a request by providing 30 documented cases of lane discontinuities across the state. While not a complete or random sample, the 30 cases nonetheless should be illustrative of the situations faced by motorists on NC roads.

The 30 cases were scattered across the state from Asheville to Wilmington. The 30 cases were all in urban or suburban areas, which makes sense because lane continuity is an issue only on roads with more than one lane in a direction at some point. By route system, there were 12 cases on interstates, five cases on US routes, one case on a US alternate route, three cases on NC routes, and nine cases on secondary routes. Ten cases had one basic through lane, 17 had two basic through lanes, two had three basic through lanes, and one had four basic through lanes.

Table 1 shows the types of lane discontinuities in the sample of 30 cases provided by NCDOT staff. Over half of the cases were of a lane add followed by a lane drop. Most often, in 11 cases, that was a lane add on the right side then a lane drop on the left. A lane drop followed by a lane add was less prominent in the sample, occurring in five cases. Five of the 30 cases were left lane drops.

Table 1. Types of lane discontinuities in NC sample.

Type of discontinuity	Diagram	Number of cases in sample
Add right then drop left		11
Add left then drop right		7
Drop right then add left		3
Drop left then add right		2
Drop right then add right		1
Left lane drop		5
Multiple		1

In terms of the distance between the lane add and the lane drop, or the lane drop then the lane add, the range was from nearly zero to 12 miles and the average was 1.9 miles. Fourteen of the 24 cases (not counting the left lane drop or the multiple cases) had a distance under 2/3 of a mile. Of the cases when a through driver was forced to make a lane change, the shortest distance in which to do so was 0.08 miles (400 feet). Figure 5 shows a short-distance case, from Hickory, NC, for the southbound through drivers, where the distance from the right lane add at point 1 to where the two left lanes are dropped at point 2 is only 900 feet. It is a lot to ask for through drivers to change two lanes in heavy traffic in 900 feet or less.

Figure 5. Short distance lane discontinuity from Hickory, NC (Google).

Based on narratives provided by the engineers who submitted the cases, there was a wide variety of reasons the lane discontinuities were allowed to happen, including:

- Nine as a result of TIP projects,
- Six as a result of land development,
- Five as a result of route number changes,
- Four because widening is expected someday,
- Three due to City involvement, and
- Three due to unknown causes.

Figure 6 shows one of the cases caused by a route number change, on I-40 near the Piedmont Triad International Airport in Greensboro. When a new loop freeway around Greensboro was designed in the 1990s, I-40 was supposed to follow it. The loop is shown as I-73 in the lower right corner of the map. On the eastbound approach to the interchange between I-40 and I-73, the left lanes were designed to head onto the loop to serve that I-40 through movement. However, within a short time after the loop was opened, it became obvious that routing I-40 onto the loop was counter-productive; most I-40 motorists continued to use the old freeway straight through town as it was shorter than the loop and quicker than the loop almost all the time. Consequently, the I-40 route number was changed back to the original route straight through town, as shown in Figure 6, but now eastbound I-40 motorists must move several lanes to the right (lanes that were added at the US-421 interchange on the left side of Figure 6) to remain on I-40.

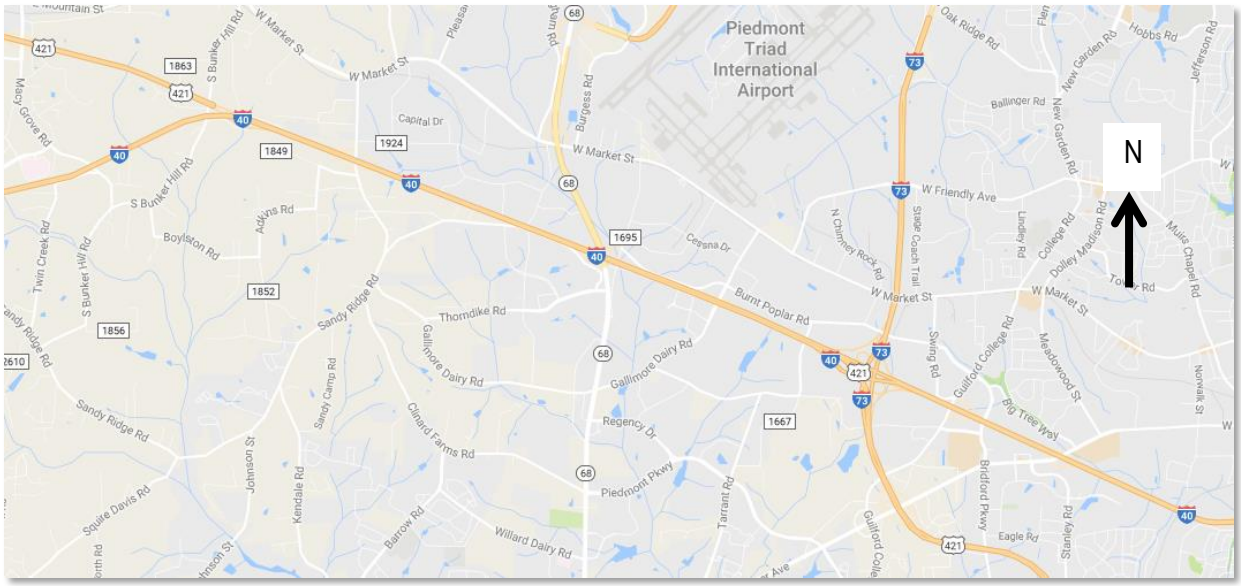


Figure 6. Lane discontinuity created by a route number change (image from Google).

In examining the discontinuities created by TIP and land development, it was apparent to the authors that many of them could have been prevented by the project engineers looking upstream from the project site and considering where the lanes originated with which they were dealing. Scope creep is a serious problem in highway projects, and we are not advocating that every project has to fix the whole corridor. However, keeping the focus too narrow during design—looking at just the traffic operations with project limits—resulted in some preventable discontinuities in our sample of sites.

Note that of the lane discontinuities resulting from TIP projects, three were fixed before opening and two were fixed shortly after opening. Of the remaining 25 discontinuity cases in the sample that are not yet fixed:

- Ten could be restriped with few apparent issues,
- Seven could be restriped but there would be negative impacts (losing capacity, making entering more difficult, or narrower lanes),
- Three are to be fixed in an upcoming TIP project,
- Three could be fixed with widening, and
- Two have no apparent solutions.

Figure 7 shows one of the ten cases that could be fixed with restriping with few apparent issues, from Morrisville, NC. The southwest-bound through movement is routed past the intersection shown in Figure 7 in the left lane, which terminates in an exclusive left turn about 1300 feet downstream. The authors have observed many through drivers surprised to suddenly find themselves in a left turn lane and making quick lane changes to return to the through lane. If the through movement was restriped into the right lane just past the intersection shown in Figure 7, lane continuity for the through movement would be preserved and there would be no more surprised drivers. There is plenty of room laterally and longitudinally for such a restriping.

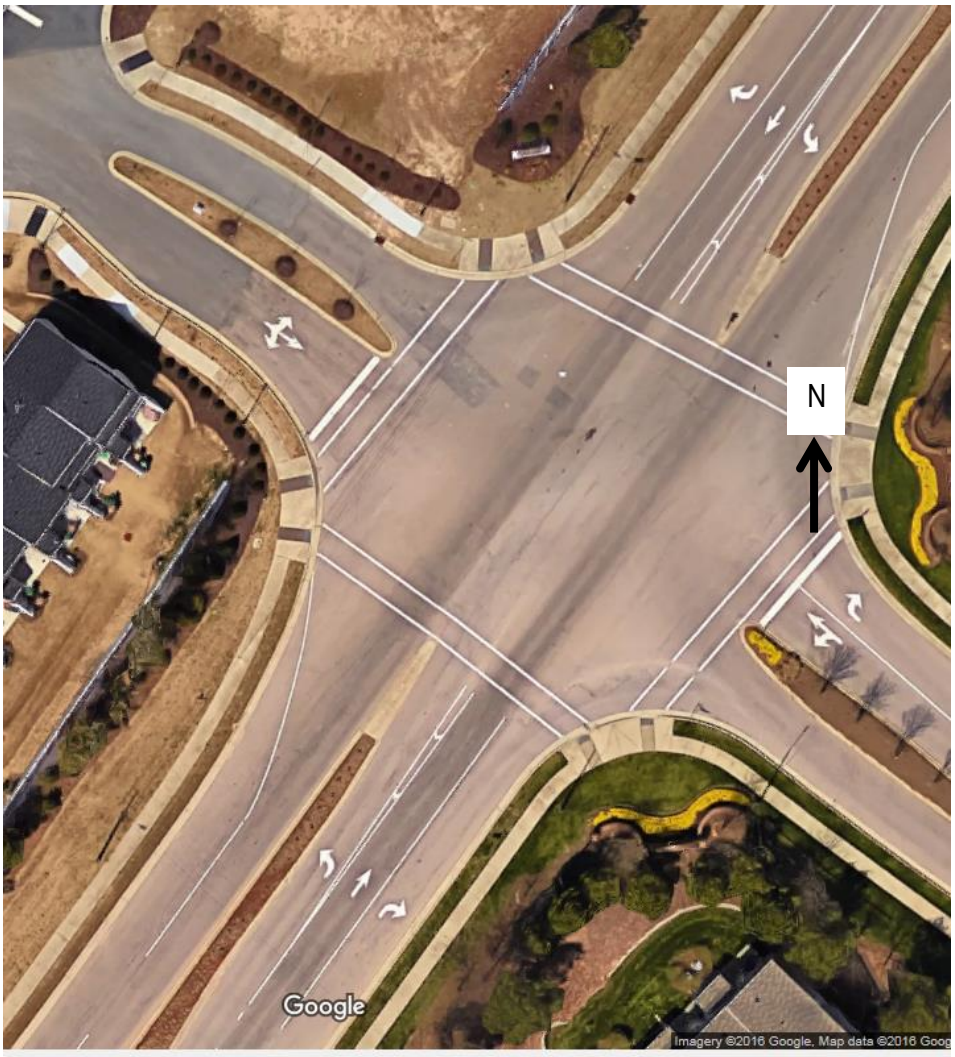


Figure 7. Case that could be fixed by restriping with no apparent impediments (Google).

POLICY

In light of the above, the NCDOT Mobility and Safety Division developed a new policy on lane continuity. The policy has two main points:

1. Reduce the number of existing lane discontinuities.
2. Minimize the number of new lane discontinuities created.

To encourage a reduction in the number of existing lane discontinuities on NC roads, the policy states that project concepts or proposals brought forward by Division staff or contractors will receive favorable consideration toward approval and funding by the State Traffic Engineer if the project or concept involves the elimination of a lane discontinuity. Concepts or proposals involving the removal of lane discontinuities on higher-volume roadways, on higher-speed roadways, on roadways with more longer-distance travelers, with shorter distances between the lane drop and add or add and drop, and/or where crash data show a clear pattern of lane change crashes will receive increasingly favorable consideration.

To make sure that few new lane discontinuities are created on NC roadways, the policy states that the State Traffic Engineer or his or her designee must provide written permission to proceed with installation or construction of:

- A drop of a basic lane on the left side of a freeway, or

- A roadway on which the distance between the drop of a basic (non-auxiliary) through lane and the addition of a basic through lane, or between the addition of a basic through lane and the drop of a basic through lane, is less than:

    - 10 miles for a primary (two-digit) interstate,
    - 5 miles for other types of freeway,
    - 3 miles for a non-freeway US or NC route, or
    - 1 mile for a non-freeway SR route.

This part of the policy applies to both work zone (temporary) and non-work zone (permanent) roadway conditions. In seeking permission to create a new lane discontinuity, Division staff or consultants must make the case in writing to the State Traffic Engineer or his or her designee that there will be minimal safety risks or travel inefficiencies created by the lane discontinuity and that there are no cost-effective ways to eliminate the proposed lane discontinuity. The State Traffic Engineer or his or her designee will base his or her decision on whether to provide permission for the discontinuity to be created on the safety risk caused by the lane discontinuity, the travel inefficiency created by the lane inefficiency, and the cost to eliminate the lane discontinuity.

The new policy puts the burden on the project engineer to recognize that their project may create a lane discontinuity and either eliminate it or justify it. The mileage limits provided in the policy were based on trying to balance realities on NC roadways with driver expectations, and may be modified later as the policy is implemented and the Division gains experience with it.

CONCLUSION

Lane continuity is the idea that a driver should not have to change lanes to follow a particular route. Lane continuity is a positive principle in street and highway design that promotes better safety, less congestion, and less stressful driving. However, a survey of NCDOT engineers revealed a non-random sample of 30 lane discontinuities on NCDOT routes, and a more complete effort would have undoubtedly shown many more. Lane discontinuities occur on NCDOT roadways in urban and suburban settings from one end of the state to the other, on a variety of types of routes. Most discontinuities involve a lane add then a lane drop. Some of our lane discontinuities have a very short distance between the lane add and drop, or between the lane drop and add. Lane discontinuities on NCDOT roadways were caused in a variety of ways, and one major underlying cause was the inability of project engineers to look upstream or downstream from their project and see how the longer corridor would function. Many of the identified lane discontinuities on NCDOT roadways can apparently be fixed fairly easily with restriping.

To promote more lane continuity, we developed a new policy within the Mobility and Safety Division. The new policy has two objectives. First, we hope to get more lane discontinuities fixed. Second, we hope to avoid the creation of new lane discontinuities.

To the extent that other highway agencies function like the NCDOT, they also very likely have created some lane discontinuities on their roadways through the years. Agencies should scan for those, take steps to mitigate them, and take steps to avoid the creation of new ones.

The obvious research need from this work is on the safety of lane discontinuities. The profession needs a model to predict the numbers of crashes caused by various types of lane discontinuities. A crash prediction model would allow the computation of benefit to cost ratios on potential improvement projects, so that engineers could compare the worthiness of those potential projects against other uses for countermeasure funding. Another useful area for future research is on lane utilization, where current models fall short in helping engineers accurately assess the effect of a lane discontinuity on capacity and level of service.

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